COMMENTS ON THE INDICES OF THE SOLAR ACTIVITY AND ITS ELEVEN-YEAR CYCLE VARIATION

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Abstract

The pattern of the eleven-year variation of the relative sunspot numbers, i.e., the Wolf numbers, is much different from that of the solar flares associated with the emissions of solar cosmic rays, type IV and great microwave impulsive radio bursts. Roughly speaking, the maximum phase of the latter is later by about three years from that of the former. It seems that such a time delay has been brought by the use of the relative sunspot numbers as the index of solar activity. Taking into account that the occurrence frequency of solar flares is approximately proportional to the relative sunspot numbers, the degree of solar activity related to the active phenomena on the sun is inferred to be closely connected with some of the nature of sunspots and their groups. It is clear, furthermore, that the pattern of the eleven-year variation of the coronal brightness with respect to the 5303Å green line emission is very similar to that of the occurrence frequency of solar cosmic-ray flares. This fact suggests that the occurrence of solar cosmic-ray flares is connected with the coronal active regions.

Some critical discussion is given on the indices of solar activity from the view points that the coronal activity is intimately connected with the active phenomena over the sun's photosphere. It is shown that the relative sunspot numbers in each of the northern and southern hemispheres must be defined as the representative index of solar activity, whenever the relative sunspot numbers are adopted.

1. Introduction

The relative sunspot numbers, which are often called the Wolf numbers, are most oftenly utilized as the index of solar activity at present. These numbers, which are defined as the R.S.N. throughout the paper, are expressed as

$$\text{R.S.N.}=k(10g+f),$$

where g, f and k are the numbers of both sunspot group and individual sunspot and the correction factor of the seeing for each solar observatory. The magnitude of the R.S.N. changes with a period of about eleven year and so is used as an index of the degree of solar activity. The increasing, the maximum and the declining phases of solar activity are always defined on the basis of the magnitude of R.S.N. at present.

Some questions have been offered on the definition of the degree of solar activity using the R.S.N. in relation to the yearly variation of the activities of solar cosmic ray flares and intense solar radio outbursts (Takakura and Ono [1961, 1962]). The maximum phase for the occurrence of such cosmic ray flares and radio outbursts was clearly not coincident with that of the R.S.N..

As was pointed out by Biermann [1962], this fact suggests that the R.S.N. does not express so well the degree of solar activity. In addition to solar cosmic ray flares, all of the maximum phase for the occurrence of solar radio type IV bursts (Boorman *et al.* [1961], Krivsky *et al.* [1966]), microwave impulsive bursts (Fokker, [1963]) and great geomagnetic storm with the range >100 gammas and SC (Obayashi *et al.* [1967]) are, also, not coincident with the maximum phase of the R.S.N..

Thus, it is necessary to find out the measure of solar activity that could define so well the occurrence frequency of transient disturbed phenomena on the sun using the above cited various phenomena. Taking into account that the solar flares associated with activities such as solar cosmic rays, radio type IV and microwave impulsive bursts and geomagnetic storms with SC take place usually around or within the sunspot groups that are most active on the solar disc, it is estimated that the magnitude of sunspot activity is to be taken up as the best measure of solar activity. However, this estimation is denied by the fact mentioned above. In consequence, some measures of solar activity must be newly defined using the activities such as solar corona and Ca-plage, for instances.

In this paper, some types of the new indices of solar activity are examined, and then the solar active regions and their nature are considered. The coronal brightness and its yearly variation are exclusively discussed here which seem to give a clue to make clear the nature of solar activity.

On the basis of the discussion considered above, the R.S.N. is again considered in re ation to the usage of these numbers as the indices of solar activity.

2. Relative Sunspot Numbers as an Index of Solar Activity

The relative sunspot numbers, which are often called the Wolf numbers, are always used as the most representative index of solar activity on the basis of the fact that these are well correlated with the geophysical phenomena such as geomagnetic activity, say Kp-indices (Kiepenhener [1953], Waldmeier [1960]). The R.S.N. varies with a period of about eleven years, during which it takes about four years from the minimum to the maximum and afterward decreases gradually.

Various disturbed phenomena on the sun such as solar flares and their related geomagnetic and cosmic-ray storms also vary with the same period as that of the R.S.N.. Consequently, the maximum phase of the occurrence frequency of the disturbed phenomena cited above has ever been thought to be almost coincident with that of the R.S.N.. Takakura and Ono [1961] have found out, however, that the most active period about the generation of Bev-energy solar cosmic rays is not coincident with the maximum phase of the R.S.N.. At the same paper, they have also remarked that the activity of microwave solar bursts has a tendency similar to that of Bev-cosmic-ray flares. The yearly variation of the occurrence of Mev-energy solar cosmic ray flares had two maxima during the one solar cycle. The first maximum at 1957 was coincident with the maximum phase of the R.S.N. (Hakura [1961], Kodama [1962], Carmichael [1962]), whereas the second maximum occurred at 1960 with the time delay of about three years (Sakurai [1967]). The yearly variation of the occurrence of solar cosmic-ray flares, Mev- and Bev-energies, during the last solar cycle, 1954-1964, is presented in Fig. 1. There are evidently two maxima, between which the peak at 1960 is higher. Although this result shows that the occurrence of solar cosmic-ray flares is intimately connected with the activity related to sunspots, the manner of this connection appears to be much complicated because of the existence of the second maximum at 1960.

In order to clarify this connection, the brightness of the solar corona is firstly considered which changes with the progression of solar cycle. The eleven-year variation of the coronal brightness has been recently examined by Antalova and Gnevyshev [1965] using the coronal green line emission, 5303Å. According to them, there are also two maxima for the coronal brightness during the one solar cycle. The pattern of the eleven-year variation of the annual mean of the coronal brightness is shown in Fig. 2 by the use of the Sacramento data on the Fe XIV 5303Å green line emission. In the figure, the monthly mean values of the R.S.N. at Mitaka, Tokyo, is also shown. These data were adopted from the CRPL-L Part B and the Monthly Bulletin of Solar Phenomena, Tokyo Astronomical Observatory. There are two maxima on the coronal brightness as in the results by Antalova *et al.* [1965], the one of which is almost coincident with the maximum phase of the R.S.N. (1957), whereas the other one is reached at 1960. These two maxima are evidently indentified with these of solar cosmic ray flares as is shown in Fig. 1. Although the sunspot activity is necessarily related to the generation of solar cosmic rays as was already dicussed, some of new types of solar activity must be sought in order for the relation between the coronal brightness and the occurrence of

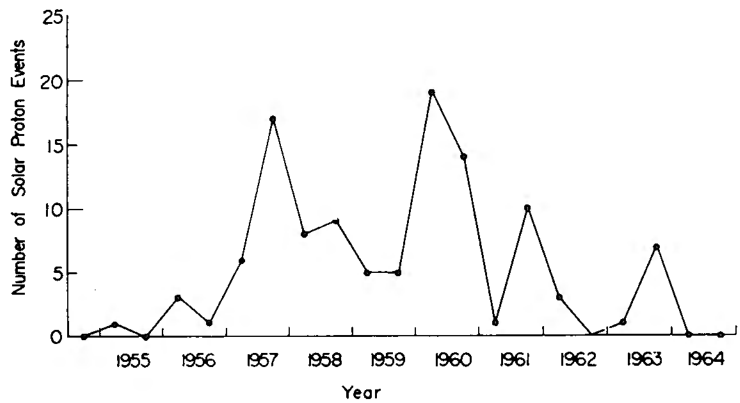

Fig. 1. Yearly variation of the numbers of solar cosmic ray flares.

solar cosmic rays to be interpreted.

The coronal activity is ultimately related with the active phenomena over the sun's surface, or the "center of activity". In reality, the degree of the coronal activity is deeply depbendent on the rise and fall of sunspot groups and their activity over the photosphere (Kiepenheuer [1953], Shklovsky [1965]). If the result shown in Fig. 2 is considered, however, it follows that the degree of the coronal activity does not change in proportion to that of sunspot activity. This fact is clearly contradict with the conclusion obtained so far that these

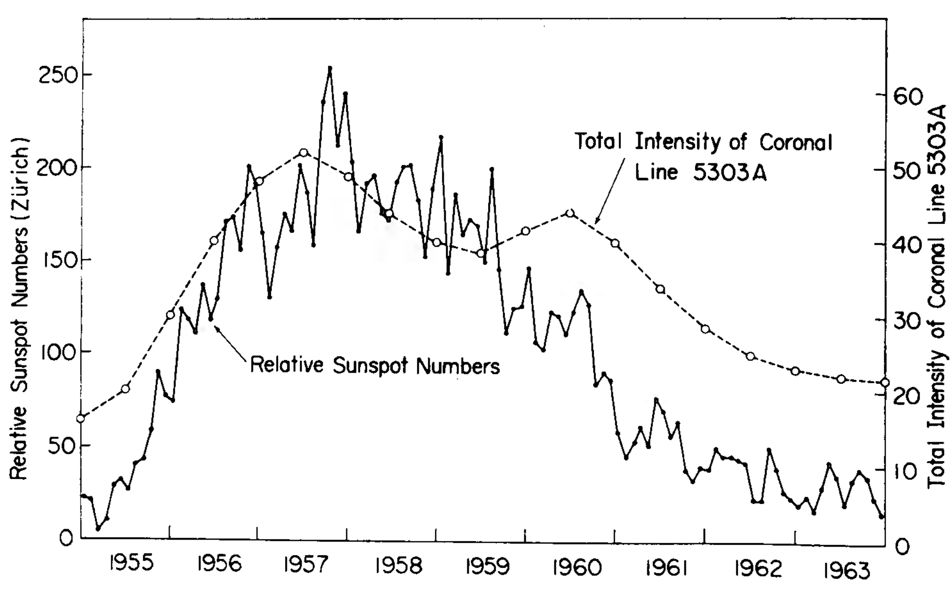

Fig. 2. Yearly variation of relative sunspot numbers, Mitaka, Tokyo and the coronal brightness, Sacramento, of 5303Å emission line.

two degrees are well correlated. Therefore, it may not be correct to utilize the R.S.N. as an index of solar activity.

The solar activity in the northern hemisphere was much higher than that in the southern one during the last solar cycle (1954-1964). Both the total numbers of sunspots and solar cosmic ray flares were in the northern much larger than in the southern hemispheres, too. In consequence, it may be necessary to consider the activities related to the photospheric phenomena separately with respect to each hemisphere, whenever these are dealt with. On the basis of the above consideration, the R.S.N.s for each hemisphere are examined. The monthly means of the R.S.N. are plotted in Fig. 3. Although these

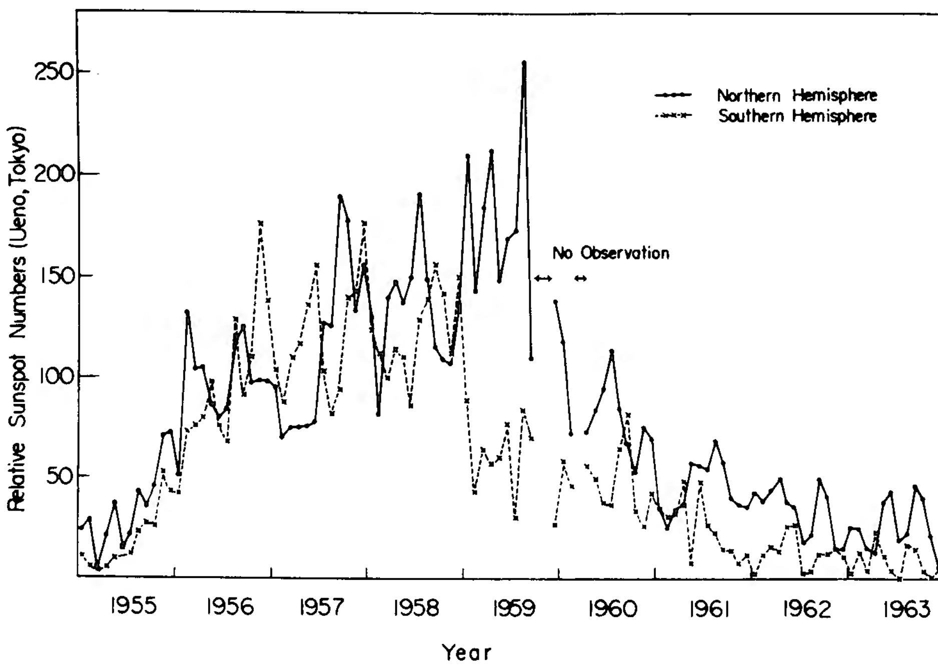

Fig. 3. Yearly variation of the relative sunspot numbers for each hemisphere, northern and southern, at Ueno, Tokyo.

two R.S.N. vary almost in the same manner till the end of 1957, the changing patterns of them are much different from each other since 1958. In the northern hemisphere, the R.S.N. continued to increase after 1958, and reached the peak about the end of 1959. Although the changing pattern of the R.S.N. from 1959 to 1960 is not understood so well because of lack of the observed data, it is clear, at any rate, that the behavior of the R.S.N. in the northern hemisphere is quite different from that in the southern one. As a result, it seems, though not well defined, that the maximum phase of the R.S.N. in the northern hemisphere has been attained earlier by about a half year from the maximum occurrence of solar cosmic ray flares. In spite of some time delay, it is led a conclusion that, roughly speaking, the maximum phase of the R.S.N. in the northern hemisphere is nearly coincident with those of both solar cosmic rays and solar coronal brightness during 1960. The yearly variation of the occurrence of solar cosmic rays as shown in Fig. 1 can be, therefore, interpreted by considering the increase of solar activity only in the northern hemisphere. In consequence, it becomes quite unnecessary to take into account both the special storage mechanism of solar cosmic ray flare energy and the triggering mechanism of such a flare that have been introduced by Takakura *et al.* [1961, 1962] to explain the result as shown in Fig. 1.

When the interpretation developed in this paper is adopted, a following question is offered naturally: what mechanism is necessary to interpret the first maximum at the second half of 1957 for solar cosmic ray occurrence? During the second half of 1957, the numbers of major solar cosmic rays were eight and seven, in the northern and the southern hemispheres, respectively. It is concluded, therefore, that the occurrence frequency of solar cosmic rays is almost equal with respect to both the hemispheres. As was already discussed (Sakurai [1967]), most of solar cosmic ray flares took place in the northern hemisphere after 1959. Hence the above conclusion seems to be very important. Since the sunspot activity during the second half of 1958 was about equal for both hemispheres as is evident from Fig. 3, it is inferred that the contribution from both hemisphere with equal magnitude made up the first maximum of the occurrence of solar cosmic ray flares.

In consequence, it can be concluded that the first maximum at the second half of 1957 was made up due to the activity of the whole sun, while the second one at the first half of 1960 was generated by only the activity over the northern hemisphere. Thus it follows that the R.S.N. to be utilized as the index of solar activity could be determined on the basis of the comparison between the R.S.N.s in the northern and southern hemispheres.

3. Coronal Activity and Solar-Geophysical Events

The pattern of the yearly variation of the occurrence of solar cosmic ray flares is well coincident with that of the coronal brightness as was already discussed (Figs. 1 and 2). This fact has been also pointed out by Gnevyshev and Krivsky [1966]. Similar results as solar cosmic ray flares have been obtained for microwave impulsive radio bursts (Fokker [1963]) and type IV radio bursts (Krivsky *et al.* [1966]). Using the observed data (Obayashi *et al.* [1967]) on type IV radio bursts, polar cap absorptions, magnetic storms with SC and cosmic ray storms during 1957 to 1963, the patterns of the yearly variation for the above various solar and geophysical phenomena are obtained as shown in Fig. 4. In the figure, the major events only are presented which are defined as follows ; polar cap absorption (Δf_{min} >5 Mc/s ; duration >6 hrs), geomagnetic storm ($\Delta H > 100$ gammas) and cosmic ray storm (intensity decrease $>2.5\%$). Since all of these events have maxima at 1960, it is concluded that they are intimately connected with the coronal activity (Fig. 2).

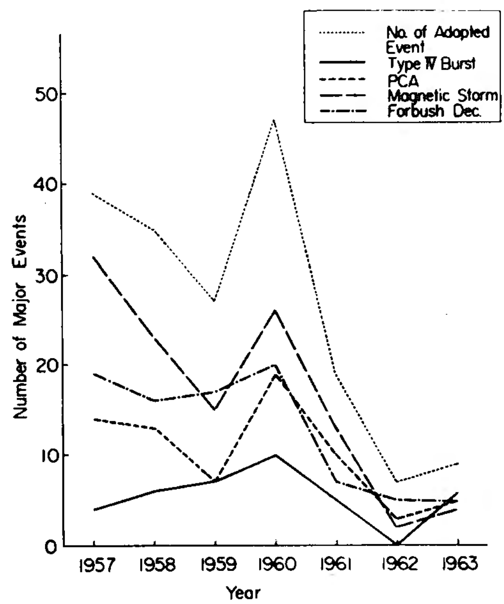

Fig. 4. Yearly variation of solar and geophysical events during the years 1957–1963.

The degree of the coronal activity is deeply dependent on that of the sunspot activity and so the main cause of solar activity lies in the rise and fall of sunspots and their groups, however, since the maximum at 1960 observed for the activities of various solar and geophysical events is inferred to be caused only through the sunspot activity in the northern hemisphere on the sun.

Many works have been made on the distribution of active regions on the solar disc since 1959. According to them, the numbers of the active regions on the sun were only two which were separated by about 180 degrees from each other. The speed of solar wind is sensitively dependent of the temperature of solar corona (T_c) and changes in proportion to $T_c^{1/2}$ (Parker [1963]). Hence, the speed of this wind becomes high with increasing the coronal temperature. Because the coronal regions with higher brightness are located above the so-called active regions, it is estimated that the speed of solar wind there is to be highest if the effect of sunspot magnetic fields is negligible. This is the cause of the 27-day recurrent variation of geomagnetic activity. On account of the action of sunspot magnetic fields, however, the highest speed of solar wind is reached at the western portion around active regions (Sakurai [1966]). It is now known that the cause of the 27-day recurrent variation of both great geomagnetic and cosmic-ray storms (Singer [1958]) and the energetic proton flows from the sun (Bryant *et al.* [1965]) lies in the localized origin of the solar active regions.

It must be remarked, as was discussed earlier in this paper, that the correlation of the coronal activity to the various disturbed phenomena of the sun and the earth is always appeared throughout the sunspot activity.

4. Discussion

The R.S.N. for the whole sun has so far been used as a representative index of solar activity, but this has been indicated to be not a good measure of true solar activity in this paper. As for the real index of solar activity, it may be correct to adopt the brightness of solar corona such as shown in Fig. 2. The coronal activity was, however, much intense only in the northern hemisphere since 1959 as in the case of sunspot activity (Sakurai [1966]). Furthermore, the active regions do not distribute uniformly on the sun's surface, but always develop around the restricted areas in heliographic longitude, the numbers of which were four and two during the years 1955-1958 and 1959-1963, respectively (Sakurai [1967]). Thus the active phenomena on the sun are generated around such restricted areas.

It is thought, therefore, that the indices of solar activity as a whole have not any definite meaning because the degree of solar activity is much different from place to place on the sun. Consequently, it seems to be natural that the yearly variation of solar cosmic ray flares is not coincident with that of the R.S.N.. Really speaking, there is a quantity for the dgree of solar activity to be expressed much better, which is the brightness of solar corona or the R.S.N. of the northern hemisphere.

The occurrence frequency of solar cosmic ray flares changes almost proportional to both the degree of sunspot activity in the northern hemisphere and the magnitude of coronal brightness. The cause of solar cosmic ray flares is evidently connected with the solar activity such as mentioned above since cosmic ray flares more frequently occur when the latter is higher. As a result, it is not necessary to assume special models on the triggering mechanisms of cosmic ray flares and the storage of such flare's energy which have so far been inferred to be important.

5. Conclusion

The index of solar activity has so far been expressed using the relative sunspot numbers, which are often called the Wolf numbers. A reason that the behavior of these numbers during the solar cycle is not coincident so much with the yearly variation of the occurrence of solar cosmic ray flares seems to be due mainly to the tendency that the active regions are only concentrated into the northern hemisphere. When the R.S.N. in the northern hemisphere is taken into occount, it follows, consequently, that its eleven-year variation is good coincident with that of the occurrence of solar cosmic ray flares such as shown in Fig. 1. Furthermore, the coronal activity shows a similar type of the eleven-year variation to the case for solar cosmic ray flares, which has been indicated to be an index of solar activity better than the R.S.N. for whole of the solar disc.

Whenever the degree of solar activity is discussed, it is, therefore, always necessary to examine the eleven-year variation of the coronal brightness and the R.S.N. in each hemisphere while considering the latitudinal distribution of both the sunspots and the coronal active areas on the solar surface.

It is very important for the investigation of solar-terrestrial relationships to utilize the coronal brightness and the R.S.N.s in each hemisphere, north and south, altogether, as indices of solar activity. When some of solar geophysical events are investigated, it is also important to examine the latitude distribution of solar flares which are accompanied by such events.

Although the causes of the north-south asymmetry of the magnitudes of solar activity and of the localized origin of the solar active regions are now quite unknown, they may be controlled by the solar magnetic field as a whole and its secular change. Future investigation must be consequently requested to consider the role of this magnetic field.

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